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13. ABSTRACT *(Maximum 200 Words)*

Report developed under STTR contract for topic AF03T019. This report documents the program objectives, work performed, results obtained, and future plans for a program to develop micro-hollow cathode discharge (MHCD) vacuum ultraviolet light sources. Significant progress was made in developing processes for fabrication of commercially viable light sources and in demonstrating that sources produced using these processes can operate for periods of time which are long enough to allow them to be used in practical applications.

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FINAL REPORT

for the project

"Ultraviolet Generation by Atmospheric Micro-Hollow Cathode Discharges"

Contract #FA9550-04-C-0002

Period of Performance: October 1, 2003 - July 31, 2004

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1. Phase I Technical Objectives

1.1 Initial Program Objectives (from Phase I proposal):

Initially, the technical objectives for Phase I of this program were to characterize the efficiency, gas temperature, and ultraviolet output flux of microhollow cathode discharge excimer lamps in xenon operating in a forced abnormal glow mode (restricted cathode area) under pulsed as well as dc excitation. A custom high power drive system was to be developed for the lamps as part of this work, and investigation into the manufacture of the cathode substrates outside a chamber was also to be performed. The goals were to demonstrate that the MHCD excimer lamp and its drive circuit are capable of meeting commercial and government needs for practical, high power UV sources, and to address some important issues for volume production of this light source.

The particular objectives of the work proposed for Phase I were to

1. Characterize the performance of lamps containing arrays of MHCD cells under dc and pulsed conditions **[Old Dominion University].**

    - *Determine optimal operating conditions for a single microhollow cathode discharge in xenon.*
    - *Vary pulse with and duty cycle for a two-dimensional array of microhollow cathode discharges to determine optimum conditions for homogeneous emission.*
    - *Analyze thermal performance of lamps to determine maximum output power for given device parameters (array density, average and peak power per cell, electrode and dielectric thickness).*

2. Design, build, and test a flexible, scalable lamp driver for performing lamp optimization tests. Driver design will lead to design of driver(s) for commercial systems. **[Ultraviolet Sciences, Inc.].**

    - *Variable parameters, including main pulse width and repetition rate, ignition voltage, sustaining current*
    - *Compact, manufacturable design*
    - *Precursor to ultimate commercial driver(s)*

3. Investigate manufacture of cathode substrate in open-air environment **[Ultraviolet Sciences, subcontracted to University of Minnesota].**

    - *Test feasibility of creating substrates of arbitrary size and shape by investigating plasma deposition technique in an open environment versus in a chamber.*
    - *Environment may have flowing gas in plasma torch region to facilitate operation.*
    - *Needed to produce lamps which can easily replace mercury or barrier discharge lamps in many commercial applications.*

1.2 Modifications to Program Objectives based on early results:

A fortuitous success in the early portion of the program led to a shift in focus during the program. The University of Minnesota team was able to demonstrate the feasibility of producing substrates in an open environment within the first two months of the program, instead of at the end of Phase 1 as expected. This success meant that we were much closer to being in a position to make a prototype commercial sealed lamp than originally expected. We now had an unexpected opportunity to attack the main obstacle to commercialization of MHCD lamps, i.e. how to produce large area lamps economically.

In view of this development, we chose to focus the resources at the University of Minnesota and at Old Dominion toward fabricating and testing these substrates in order to optimize the deposition process steps, rather than varying the way the hand-built MHCD sources were driven as originally planned. This new direction was clearly the path which would lead to a useable ultraviolet system in the shortest amount of time, which is why we chose to follow it. Optimization of the MHCD light source's structure and operating conditions in a laboratory environment holds no guarantee that those parameters will be optimal for a sealed, long life lamp. Even if the optimization had been completed using foil-manufactured devices, a significant part of the work would have needed to be repeated using the plasma-deposited substrate to ensure that the optimal operating point was the same. By taking advantage of our early success in forming the plasma deposited substrates, we have significantly shortened the time which will be required to field a usable light source.

2. Description of Work Performed

This section contains separate narratives of the work which was performed in each of the three focus areas – substrate development, optimization of source geometry and testing of new substrates, and lamp driver development.

2.1 Substrate Development – University of Minnesota

These tasks are directed toward developing the best and most economical manufacturing process to form the MHCD light sources. After reviewing a number of possibilities, plasma spraying of the dielectric layer onto a molybdenum electrode using yttria stabilized zirconia (YSZ), and of the top electrode layer by spraying molybdenum was selected the initial approach. In preparation for the initial experiments, powders were procured and four-sample substrate holders with masks for the zirconia and molybdenum layers were machined. Also, a 2 kV "hi-pot" device was assembled to test the dielectric strength of the insulating layer of the substrates. The initial approach was to use a commercial SG 100 plasma spray torch (Praxair Surface Technologies) to deposit a dielectric layer on a 500 μm thick molybdenum substrate, and then deposit a molybdenum layer on top of the dielectric layer. The discharge holes were drilled after the fabrication of the three - layer structure.

2.1.1 First Generation Substrates

The first task in the lamp fabrication process was the optimization of the spray parameters for the dielectric coating (powder used was 80% ZrO_2 20% Y_2O_3; Praxair P/N AI-1066). The manufacturer's suggested operating conditions were used as a starting point. The parameters were then adjusted to give the highest particle velocities and temperatures within the limits of the system. The particle velocities and temperatures were measured with the ThermaViz

system from Stratonics. The higher particle velocities and temperatures would give a denser coating, and as a result, a higher dielectric strength. The dielectric was sprayed at approximately 4 grams per minute for 10 minutes; the torch was traversed over one minute to give an even coating. This yielded a dielectric coating of 380-400 μm with a voltage withstand of 1300-1800 V. The manufacturer's suggested operating parameters were used for the subsequent deposition of the molybdenum layer (ALLDYNE; P/N MO-7309). The torch operating parameters are shown in Table 1, a general schematic of the set-up is shown in Figure 1, and a diagram of the substrate holder is shown in Figure 2. It was found that a beveled edge on the mask would allow removal of the sample without delaminating the coating. The substrate holders were mounted on a rotating wheel which rotates at approximately 30-40 RPM.

Powder	Molybdenum	Zirconia
Current (A)	600	900
Ar (psi)	60	40
Ar (slm)	56	41.9
He (psi)	90	40
He (slm)	17.7	8.9
Carrier (Ar, psi)	15	30
Carrier (Ar, slm)	2.8	4.5
Standoff (mm)	90	96

Table 1. Torch operating conditions

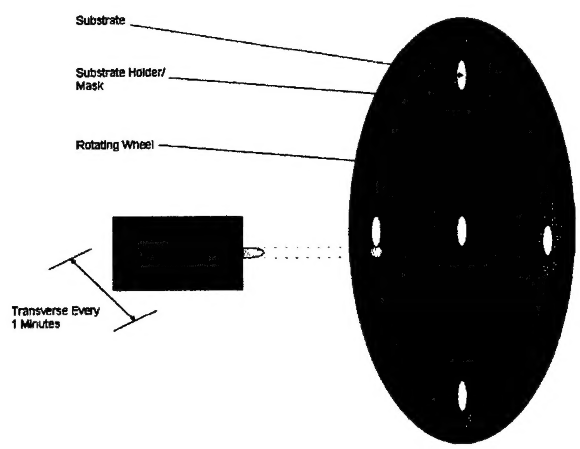


Figure 1: General schematic of plasma deposition apparatus.

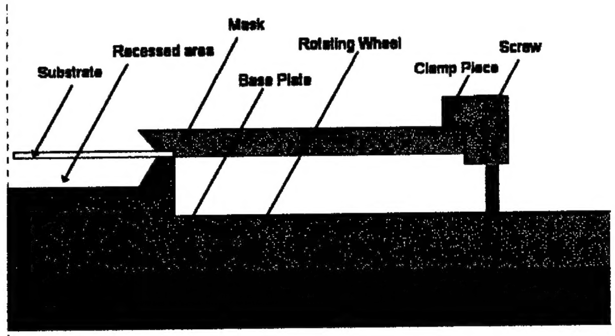


Figure 2: Diagram of the substrate holder.

After the process parameters had been established, the first set of prototype substrates were shipped in late November to Old Dominion University for discharge testing. A second set was shipped in mid-December, and a third set was shipped at the end of December.

While we were successful in manufacturing plasma-deposited devices at this early stage of the program, these devices were not durable enough to be successfully tested. Due to difficulties with the Nd:YAG laser at ODU, the openings in the initial substrates had to be drilled mechanically. The plasma-deposited material in some cases cracked under the mechanical drilling and in others partially disintegrated in the ultrasonic cleaning bath. The sources demonstrated only a few minutes of life, which was much shorter than that for sources with the same geometry which were manufactured by hand at ODU from separate foils and glued together. Also, the thickness of the dielectric layer varied by as much as 25%, which was unacceptable for consistent lamp properties from one sample to the next.

2.1.2 Second Generation Substrates

Because of the problems associated with the drilling of the discharge holes through three layer structures, substrates were used with predrilled holes in the next set of samples. A recessed area was placed behind the substrate before spraying to catch the powder which traveled through the hole (see Fig. 2). Holes of various diameters were drilled, and a diameter of 0.75 mm was chosen as the standard.

Since the spraying of the molybdenum layer on top of the dielectric layer resulted in unacceptable reduction of the voltage withstand due to molybdenum entering the predrilled hole, the plasma spray deposition of the top electrode layer was temporarily abandoned in favor of gluing a molybdenum metal sheet onto the dielectric layer.

Furthermore, the deposition process for the YSZ layer was modified by (i) increasing the layer thickness from about 150 to 250 μm to 300 to 400 μm; (ii) introducing a heat treatment step after the dielectric layer deposition. This heat treatment resulted in further densification of the YSZ dielectric layer improving its dielectric strength and reducing its deterioration during operation. It was found that the optimal temperature for heat treatment was between 600 and 650 °C. The heat treatment resulted in porosities which were between 2.5% and 9% lower than those of the samples which were not heat treated. Several samples were prepared

for microstructural analysis by sectioning them, and by polishing the cross-sections. The characteristics that were investigated were porosity and grain size as well as possible crack formation for samples (i) right after deposition, (ii) after heat treatment, and (iii) after operation of a micro-discharge, in particular when deterioration of the source discharge characteristics were observed. A heat treated sample cross section is shown in Fig. 3, and an as-sprayed sample cross section in Fig. 4.

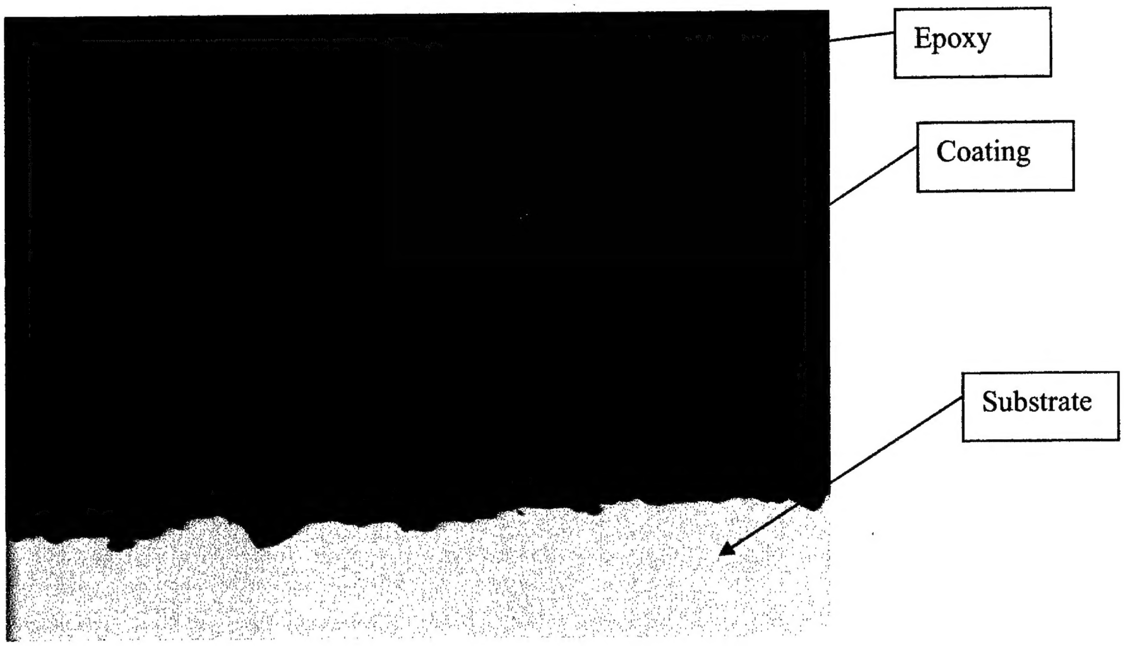


Figure 3: Heat-treated sample - 20 min at 500-700 °C; 10x magnification

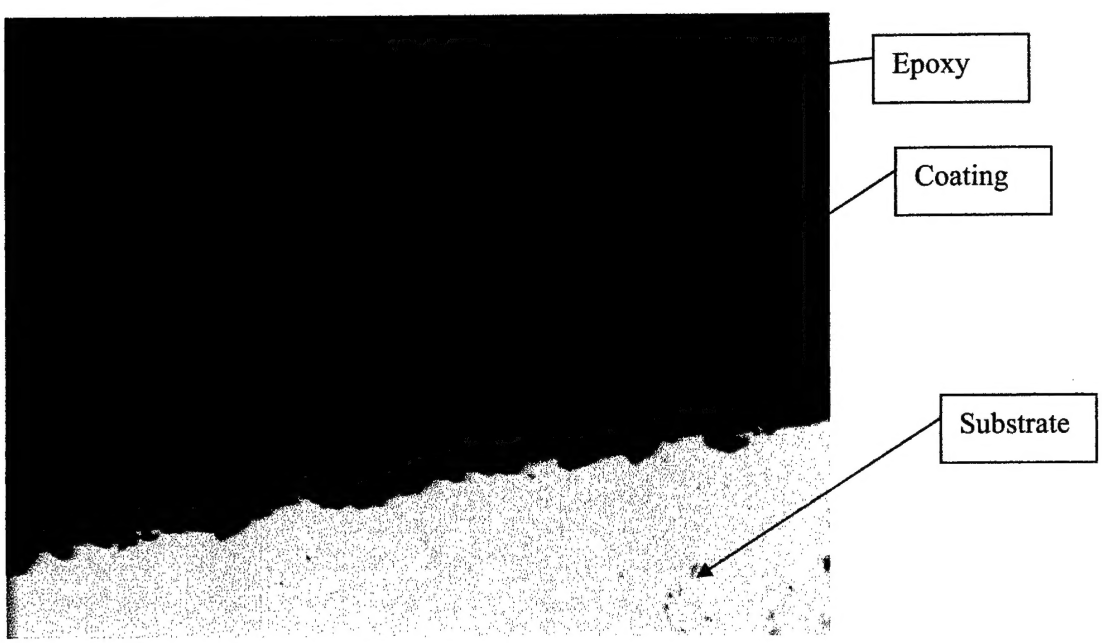


Figure 4: As-sprayed sample: 10x magnification

Several sets of samples were prepared and sent to Old Dominion University for evaluation as micro-discharge sources. The table found in Appendix D lists the prepared samples with appropriate comments. The "densified" samples displayed better performance than those which were not heat treated in the tests at ODU. The detailed results from these samples are presented below.

2.1.3 Third Generation Substrates

After the successful demonstration that a sample consisting of a predrilled molybdenum substrate with a plasma sprayed YSZ layer and a molybdenum plate glued to the YSZ as the second electrode can perform as a micro hollow cathode discharge lamp, our efforts were once again directed towards manufacturing a three layer substrate with a 0.75 mm hole in two of the three layers using plasma spray processing. The newly developed process worked as follows. After depositing the dielectric layer, a plug matching the diameter of the hole was inserted into the hole. Then, the molybdenum layer was deposited onto the sample. After deposition, the plug was removed. A diagram of the covered hole is shown in Figure 5. To obtain sufficient strength, a 200-350 μm molybdenum coating was deposited.

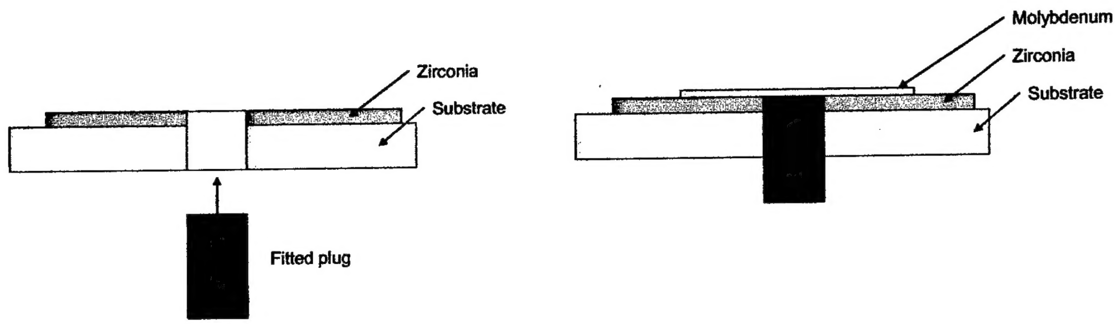


Figure 5. Three layer substrate formation.

A typical sample of the plasma-deposited 3 layer sample is shown in Fig. 6.

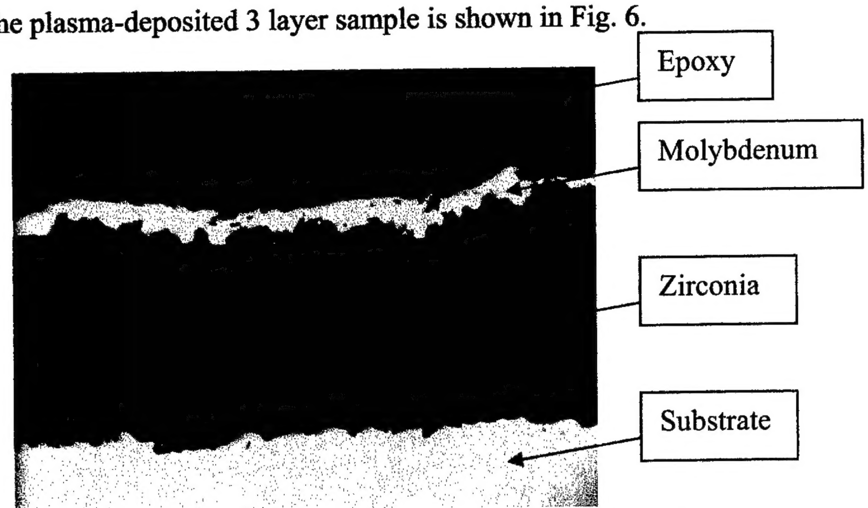


Figure 6: Three layer plasma deposited sample; not heat treated

The first of these samples has been tested for their performance as MHCD sources. It is planned to try shaping the fitted plug to form the micro-hollows in the cathode layer. If this

fails, the next step will be to attempt to drill the micro-hollows mechanically and/or with a laser.

In parallel to the development of the plasma-deposited three layer substrates, Ultraviolet Sciences has been working with a local company to develop techniques to braze the cathode onto a two layer structure. These efforts are in their initial stages, and no results have been achieved so far.

2.1.4 Summary

An economical and scalable process was developed for manufacturing a two-layer assembly with a hole for a micro-discharge which can operate satisfactorily as a UV light source with a third metal layer attached to it. A further development of this process with deposition of the third metal layer shows promise but requires testing and optimization. A separate effort to braze cathodes onto two layer substrates is underway as well, but no results have been achieved as yet.

2.2 Optimization of source geometry and testing of substrates:

The plan for selecting the optimal geometry for the individual micro-hollow cathode discharge cells was to assemble them using individual molybdenum and zirconia foils until the plasma deposited substrates were ready. This plan was carried out, but damage to the Nd:YAG laser forced us to use mechanical machining of the discharge cells to produce the initial results presented below. This produced acceptable results for the discharge cells assembled with foils. The first generation of devices formed by plasma deposition which survived the machining and cleaning process did not perform as well.

2.2.1 First generation sources

The results achieved with the initial foil-manufactured devices agreed with that of past experiments. The specifics of the initial foil-manufactured cells are:

1. Dimensions

1) Cathode:	Mo, 500 µm thick
2) Anode:	Mo, 100 µm thick
3) Dielectric:	Al_2O_3, 250 µm thick
4) Diameter of anode opening:	750 µm

2. Sample Fabrication (Procedure)

   1) Drill through anode foil and dielectric, using a diamond drill bit ($\Phi = 0.75$ mm)
   2) Polish cathode surface (411Q WETORDRY TRI-M-ITE paper Awt. W 600 No.3, polishing liquid: ALPHA MICROPOLISH II DEAGGLOMETRATED ALUMINA 1.0 BUEHLER 1.0 MICRON)
   3) Ultrasonic cleaning of cathode-medium: distilled water; time: 20 min
   4) Connect cathode, dielectric, and anode, using glue at the outer edges
   5) Electrical contact: pressure contact for cathode and anode

The specifics of the initial plasma-deposited cells are:

1. Substrate Dimensions
   1) Cathode: Mo, 500 μm thick
   2) Anode: Mo, 140 - 175 μm thick
   3) Dielectric: Al_2O_3, 140 - 175 μm thick

2. Sample Fabrication (Procedure)
   1) Drill through anode layer and dielectric into the cathode layer, using diamond drill bit (Φ = 0.75 mm)
   2) Ultrasonic cleaning of sample-medium: distilled water; time: 5 min

Figure 7. Cathode surface shows grooves caused by mechanical drilling.

The results achieved with the foil-manufactured sample are below.

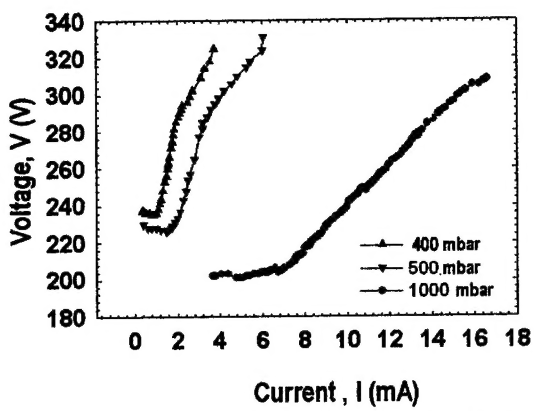


Figure 8. I-V characteristic of foil-manufactured sample

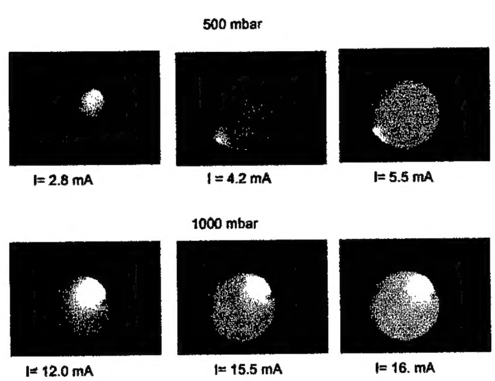


Figure 9. Images in the visible spectrum. At lower currents we see self-organization.

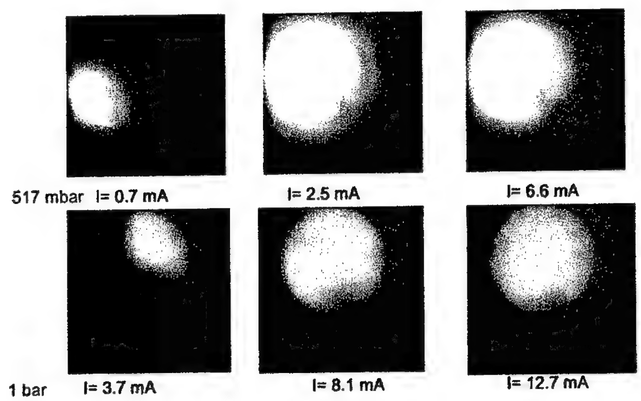


Figure 10. Images of the discharges at 172 nm (VUV). Highest intensity is seen at 500 mbar, 2.5 mA. The intensity decreases with current

The results achieved with the plasma-deposited sample are below

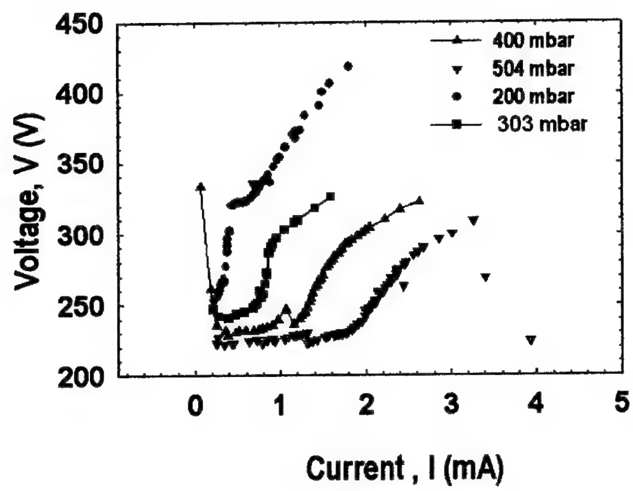


Figure 11. I-V characteristics for first generation plasma-deposited sample. The discharge becomes unstable above a certain current, which is below that of the foil-manufactured sample.

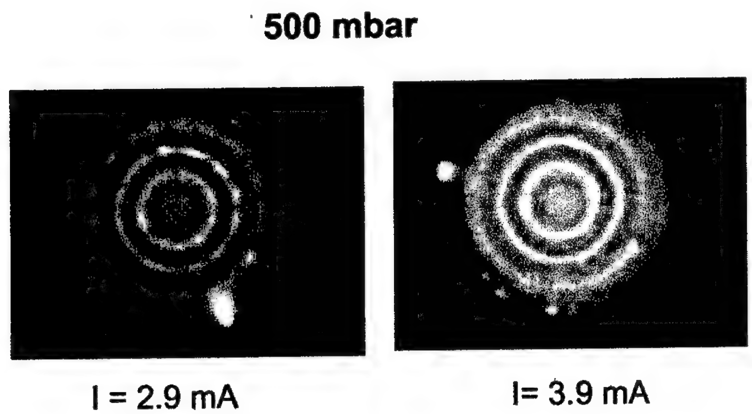


Figure 12. Images of the plasma deposited substrate in the visible spectrum. Note that the structures match the machining marks on the cathode (see Fig. 7)

The I-V characteristics of the devices are similar up to the point at which instabilities appear in the plasma deposited source. These instabilities are thought to be a result of the mechanical machining processes. The grooves in the cathode are potential sources of instabilities, as is deposition of cuttings and other impurities on the dielectric surfaces.

2.2.2 Second generation sources

A number of the problems encountered with the first generation of plasma deposited sources were overcome in the design of the second generation sources described in Section 2.1. The result of this work is that we operated a plasma deposited sample for over 30 hours, which is a factor of 3 longer than any previous MHCD source has operated. The 172 nm UV output of this MHCD source is substantially higher in both intensity and efficiency than that of any commercially available lamp of which we are aware. There is more work to be done before lamp life in the 1000's of hours is demonstrated, but this performance is a large step toward achieving that goal.

The performance data for the 30 hour test is below. The sample was prepared by gluing a 500 um thick molybdenum cathode layer onto the device (see Figure 13), installing it in the vacuum chamber, pumping the chamber down and holding the vacuum for 18 hours,

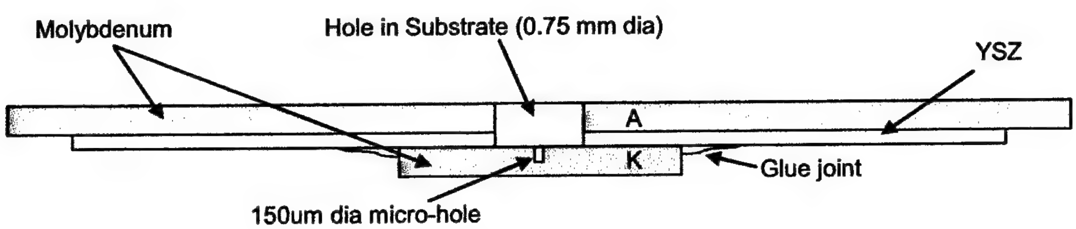
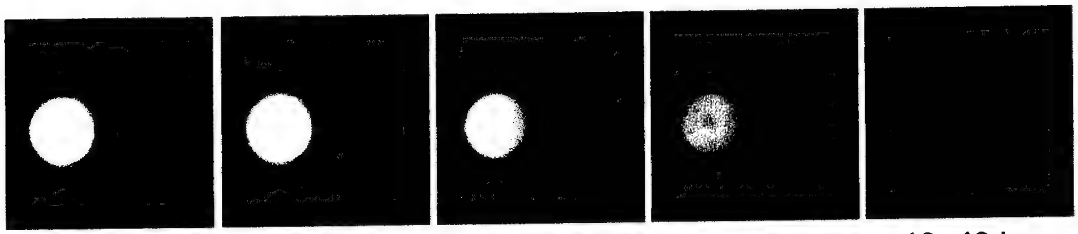


Figure 13. MHCD test source configuration

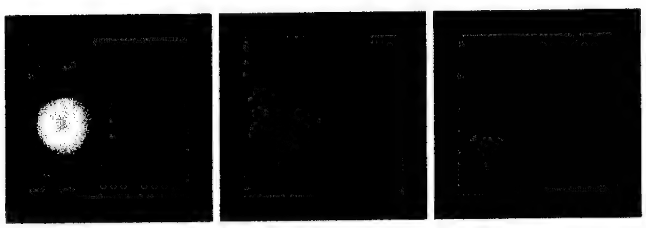
then filling the chamber with xenon to 400 mbar. The device was then powered on and the current adjusted to a point at which the maximum output efficiency was reached. The source was then operated for 30 hours before it was necessary to stop to prevent damage to the device due to the constriction of the discharge (Figure 14). The chamber was then purged

and refilled with xenon. The discharge was then restarted, but the source almost immediately reverted to the constricted discharge displayed before purging and refilling the gas. The chamber was then placed under a vacuum again for the same 18 hour pump-down cycle as was performed before the device was initially started. After this the device was set at the same 0.95 mA current as before and operated for 30 hours before the test was stopped. The results are shown below in Figures 14-16.



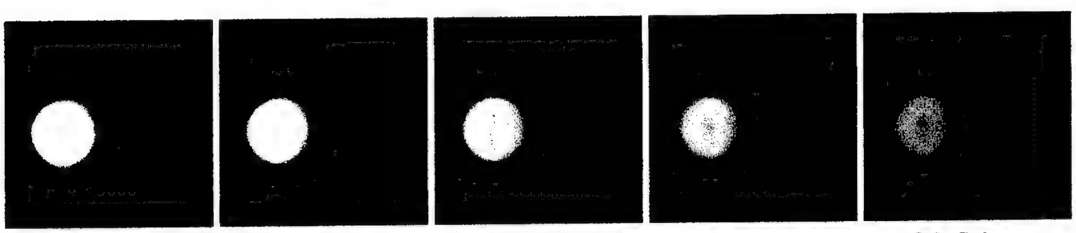
0 hrs   5. 55 hrs   8. 55 hrs   13. 00 hrs   19. 40 hrs

Figure 14. UV output of MHCD device after initial 18 hour evacuation.



0 min   5 min   7 min

Figure 15. UV output after initial 30 hour operation, gas purge and refill.



0 hrs   13.2hrs   19.3 hrs   25.3 hrs   30.3 hrs

Figure 16. UV output after 18 hour evacuation, 30 hr operation, and 2[nd] 18 hour evacuation.

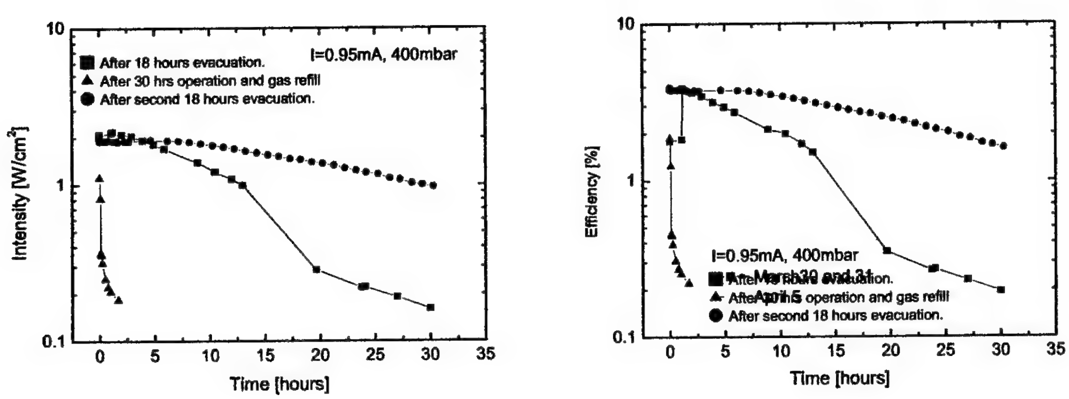


Figure 17. Measured 172 nm UV intensity and calculated efficiency over time for a plasma-deposited MHCD device.

While this result was an important step in the development of a commercial light source, the glued-down cathode, long pumping time (at room temperature), and post fabrication drilling prevent this device from being viable in a fieldable system. For these reasons, this test was stopped after the 30 hour run, so that focus could be placed on MHCD cell types which are closer to those which will ultimately be used in practical lamps.

2.2.3 Third generation sources and optimization tests

While the work at UMN on directly fabricating the third generation sources was being performed, some of the geometry optimization tests were performed using some of the remaining second generation substrates. Individual cells with flat cathodes, with one 150 um hole, and with five 150 um holes were tested. Figure 16 shows the spatially resolved UV output of the flat cathode source, which was formed using a second generation two layer substrate with a flat molybdenum plate glued onto it.

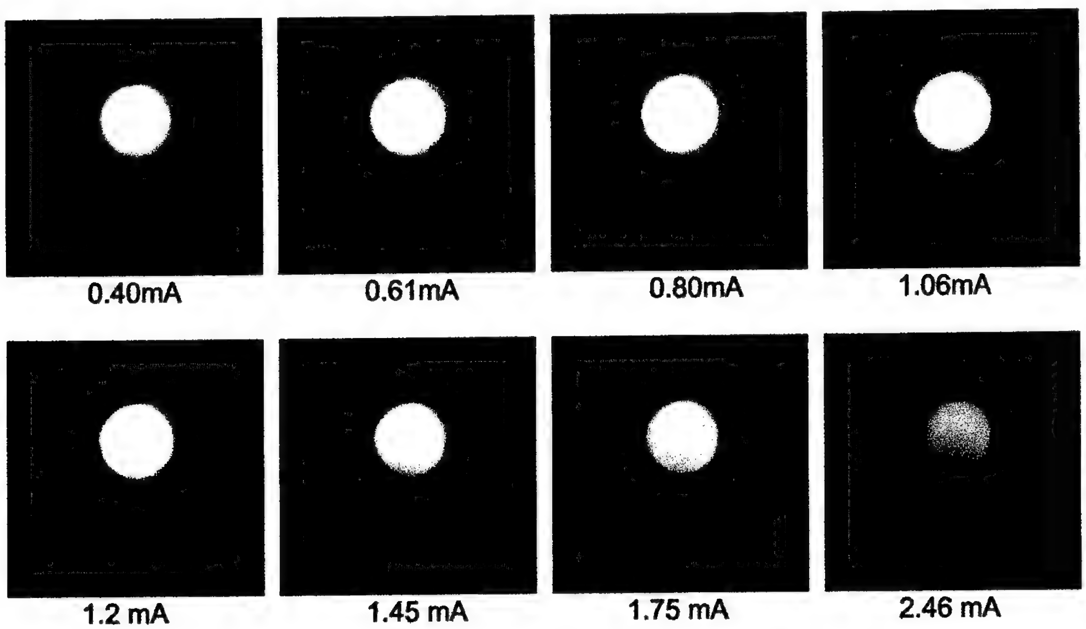


Figure 18: Spatially resolved UV output of flat cathode source

When the first set of third-generation sources was received, these were tested as well. Figure 19 below has photographs focused on the anode and cathode of one of the three-layer plasma-deposited third generation sources.

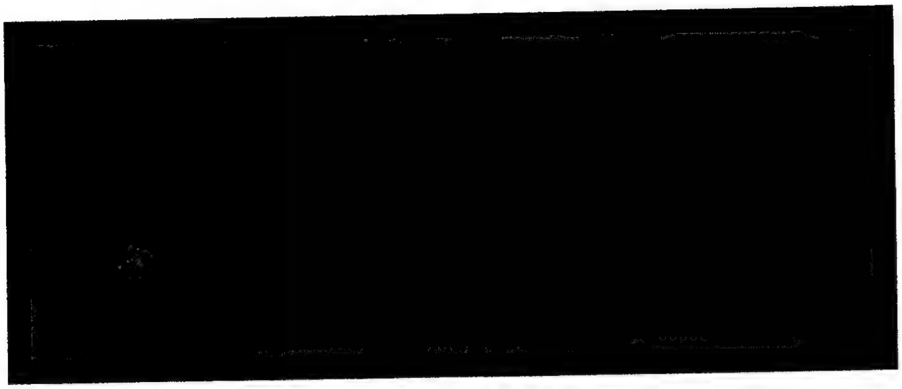


Figure 19. Anode surface (L) and cathode surface (R) of three-layer plasma-deposited third generation source.

Figure 20 shows the spatially resolved UV output for one of the three-layer plasma-deposited third generation sources. Note that the cathode roughness causes some non-uniformity in the UV intensity which appears to remain even at the maximum light output. This was not seen in other devices, including those which had some cathode surface roughness. We will investigate this phenomenon further in our future work.

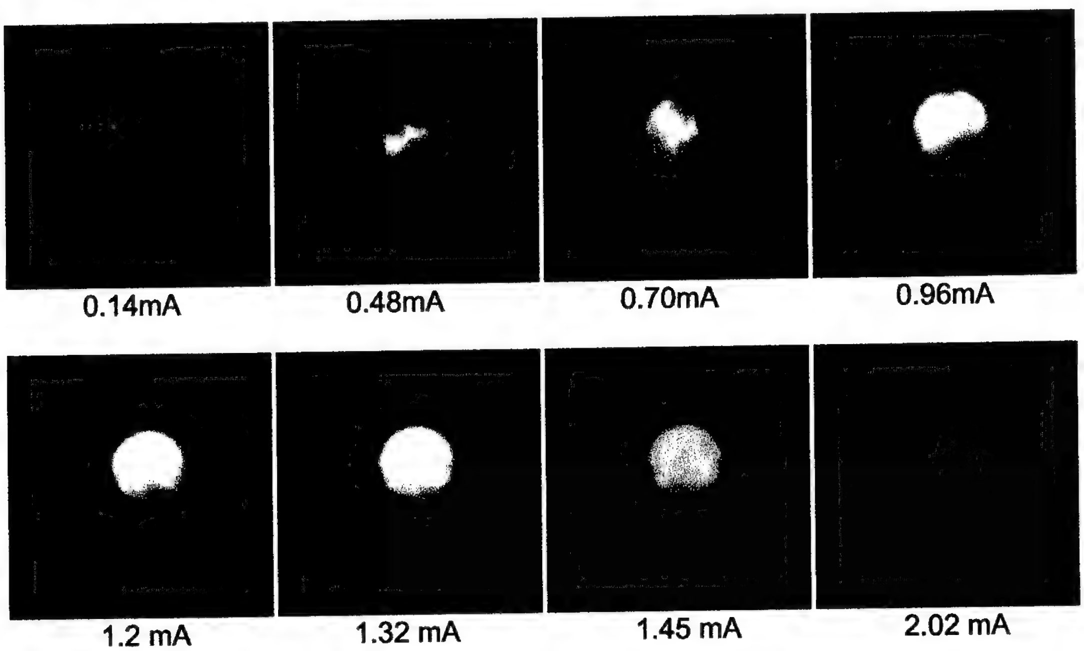


Figure 20. Spatially resolved UV output from the three-layer plasma-deposited source.

The results collected from operating the flat cathode, one-hole, and five-hole second generation sources and the third generation source are presented below. While these results show some possible trends in device operation, the tests must be repeated with several devices of each configuration before the results can be used to optimize the individual cell geometry.

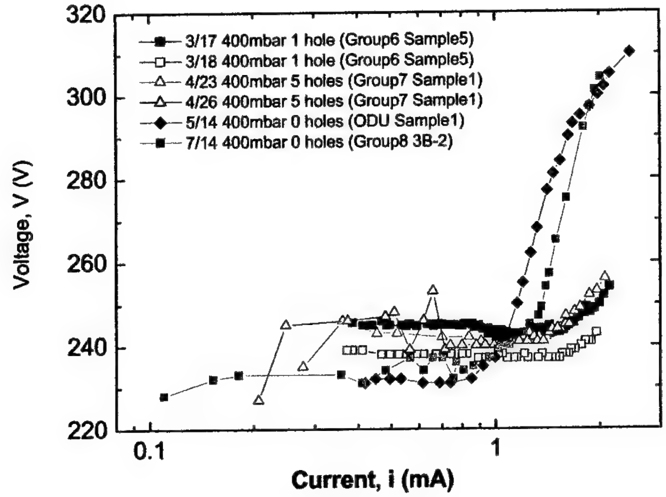


Figure 21. I-V characteristics of flat cathode, one-hole cathode, five-hole cathode, and third generation (3B-2) devices.

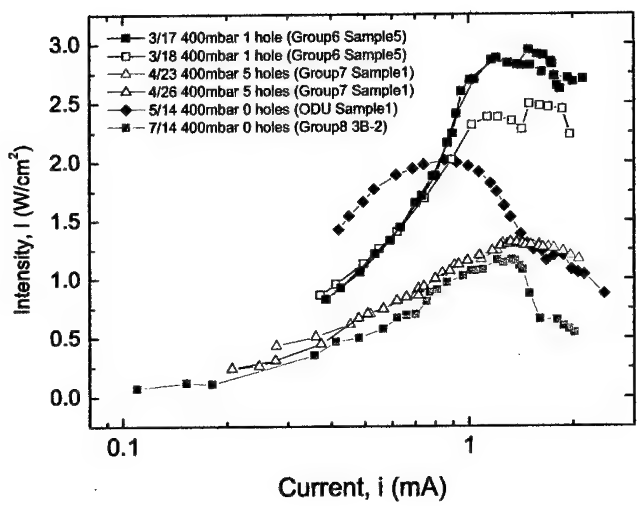


Figure 22. UV intensity of flat cathode, one-hole cathode, five-hole cathode, and third generation (3B-2) devices.

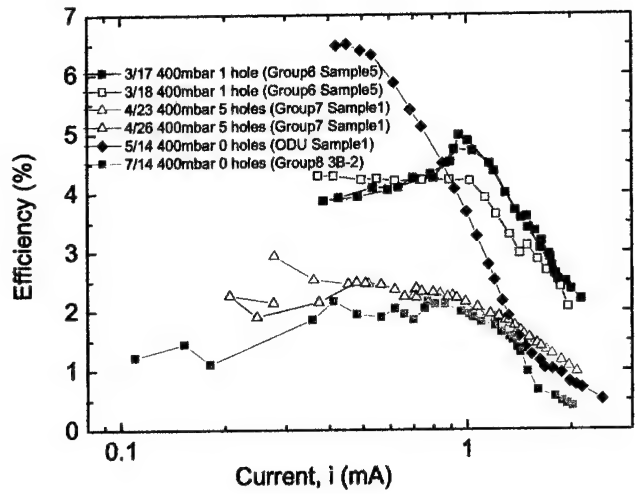


Figure 23. Wall plug - UV efficiency of flat cathode, one-hole cathode, five-hole cathode, and third generation (3B-2) devices.

As mentioned above, more testing with a larger number of devices is required to validate these results. The results to date indicate that the MHCD light sources are substantially more intense and more efficient in UV production than competing sources.

2.2.4 Summary

These data demonstrate that MHCD lamps can produce UV intensities which are at least an order of magnitude higher than the best available lamps today. In addition, the 5%+ efficiency demonstrated with some of the devices is at least a factor of two higher than the best mercury lamps on the market. Demonstration of 30 continuous hours of lamp operation (compared to less than 1 hour for previous samples) is a large step toward commercially viable lamps.

While these results are very promising, it should be noted that these data were generated using only one sample of each configuration, and that the construction techniques for the lamps are not the same in all cases. We plan to repeat these tests with other devices with the same geometry and to also test devices which have the characteristics necessary to be used in commercial lamps.

2.3 Development of Lamp Driver:

The first step in this work was to develop a specification for the lamp driver. The specification agreed upon by the team members is reproduced as Appendix E. A preliminary design was completed early in the program and several components were ordered for assembling the unit based on this design

A key feature of the design is the high frequency voltage multiplier. As mentioned in the proposal for this program, such a high frequency voltage multiplier network has been investigated for producing the high voltage ignition pulse for the lamps. It was determined

during the preliminary design period that the same circuit can also be used to provide the sustaining current for the discharge. A SPICE simulation circuit of the voltage multiplier circuit is shown below, along with the waveforms generated by the circuit.

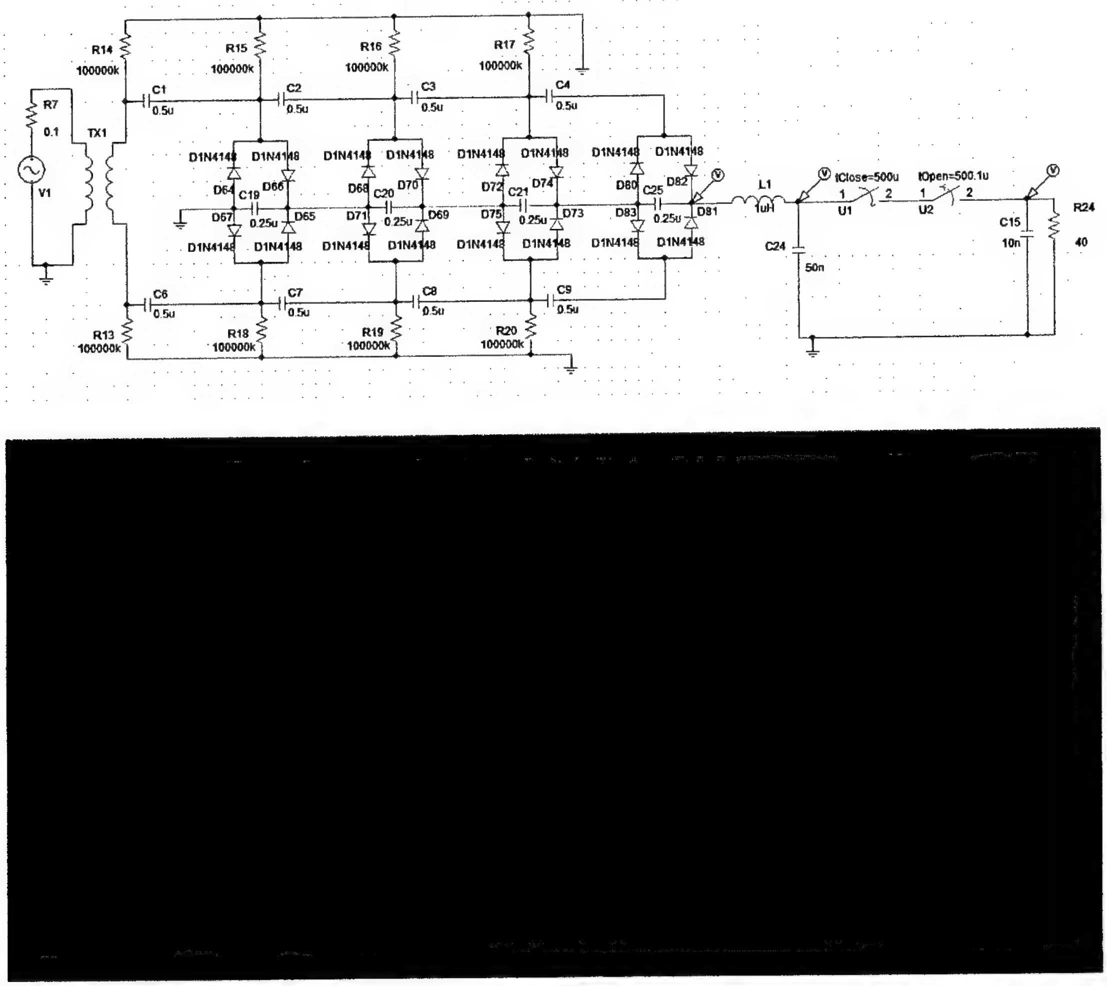


Figure 24. Voltage multiplier simulation schematic and output waveform.

The blue trace shows the voltage at the load. Note that the voltage comes up to almost 1200 V (Scale is shown as 0-120 V), then drops to around 200 V after the "breakdown" occurs. The circuit will sustain this voltage indefinitely. Should the discharge extinguish, the voltage at the load will climb back up to the 1200 V level. Also, the series impedance of the voltage multiplier network will limit the current, which will control the power delivered to the load under normal operation as well as in the event of a load fault. This dynamic performance matches the requirements of the load very well, so the voltage multiplier circuit alone can be used both to initiate and sustain the discharge. To mitigate risk should unforeseen problems occur, a conventional switching power supply will be incorporated into the prototype as a backup means to sustain the discharge. To achieve the pulsed performance specified, the unit has output MOSFETs to switch the voltage from the high voltage multiplier on and off with a continuously variable 10-100 ns conduction time range.

After the preliminary design and circuit simulations were completed, the decision to pursue optimization of the substrate manufacturing process instead of the device configuration and drive parameters was made. As a result, the lamp driver was not needed as early in the program as originally planned. Due to the lack of experience with this circuit, it was decided to assemble breadboard versions of the key circuits to compare performance of real circuits with the simulations performed earlier. While delaying the scheduled delivery of the power unit, this work greatly reduced the chances that there will be unforeseen problems when the prototype was first assembled and operated. The breadboard circuits were assembled and tested and the design methodology for the circuit as well as the design values for the components have been validated. The actual circuits had output voltages and currents which were within 10% of the values generated by the simulated circuits in all cases, which is very good agreement.

The components for the prototype were then selected, a bill of materials was created, and the components were ordered and received. Sourcing of the custom transformers for this program proved to be problematic, so Ultraviolet Sciences designed and built the transformers ourselves the prototype drivers. The prototype lamp drivers have been assembled and are currently under test. Figure 25 shows one of the lamp drivers prior to installation of the magnetics and wiring harness. This unit has been designed for 2 kW average power. Given the efficiency displayed above, this unit will drive a lamp with a UV output of at least 100W. A production unit at this power level is expected to be less than ½ the size of this prototype.

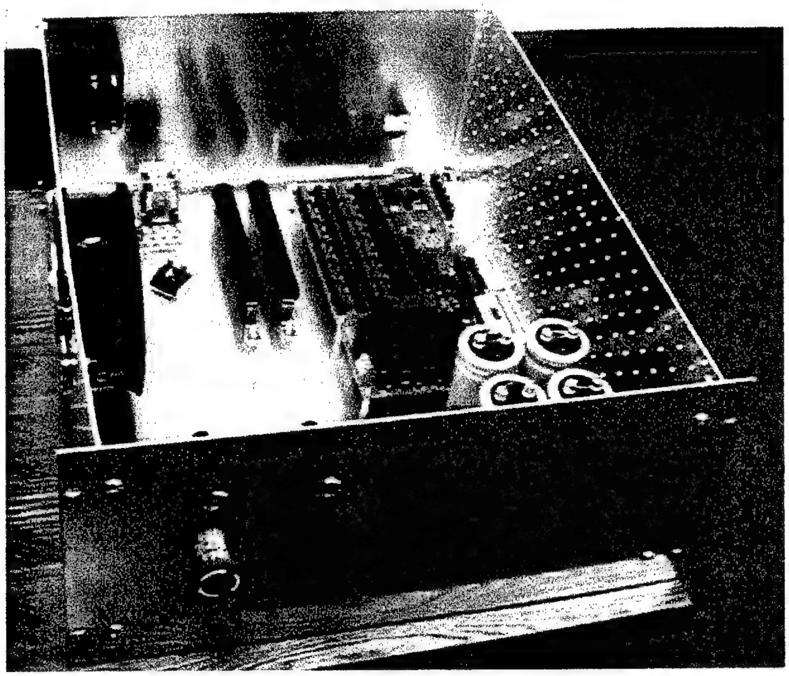


Figure 25. Prototype lamp driver.

One lamp driver will be delivered to Old Dominion when testing is complete to allow for pulsed operation of the devices and to test the unit under well-defined load conditions. The other will be used at Ultraviolet Sciences to drive the sealed prototype lamps when these

lamps become available. The manufacturing and material costs of these drivers are such that the overall system will be cost-competitive with existing commercial VUV systems.

In summary, a novel circuit for driving MHCD lamps was designed, breadboarded, and is currently being bench tested as part of a full lamp driver system. This circuit matches the lamp electrical characteristics very closely, which leads to a driver with minimal size and best efficiency when compared to other candidates for the lamp driver.

3. Discussion of Phase I Program Results

The detailed results of our work are described in the previous section. Overall, the results achieved in this Phase I effort have brought a commercially viable MHCD-based vacuum ultraviolet light system even closer to being a reality than was originally anticipated in our Phase I proposal. This successful outcome is a direct result of the flexibility and creativity of the research institutions who were partners in the program. Two of the major accomplishments in Phase I, developing a low-cost manufacturable substrate and demonstrating lamp life measured in tens of hours instead of a few minutes, were on the critical path for the overall system development and were not expected to be achieved until Phase II. Due to these accomplishments, we will be able to begin testing of sealed lamps for commercial applications much sooner than originally planned.

4. Plans for Future Work

Ultraviolet Sciences is committed to producing vacuum ultraviolet systems employing MHCD sources to produce the light, and will continue the work which was begun in Phase I even after the end of the Phase I program. Funding our Phase II proposal would greatly expedite the development of this product, and would certainly accelerate the deployment of practical MHCD-based light systems, particularly those with characteristics desirable for Air Force applications. This work will include those tasks already outlined in our Phase II proposal for continuation of this work.

Appendix A. Cumulative list of Program Personnel

The personnel who performed this work are listed below by organization:

Ultraviolet Sciences, Inc.:

J. R. Cooper (PI)

University of Minnesota:

Joachim Heberlein (PI)
Guang Yang
David Outcalt

Old Dominion University:

Karlheinz Schoenbach (PI)
Abdel-Aleam H. Mohamed
Nobuhiko Takana

Appendix B. List of Publications produced under the Program

No publications were produced or are in progress on this work at the present time. Any publications will be submitted to the AFOSR program manager for approval for publication, and will have the sponsor information properly displayed.

Appendix C. Invention Report – DD Form 882

No inventions have been disclosed or filed, nor are any disclosures or filings in progress on this work at the present time. Any IP will be governed by the contract terms and the IP agreements in place between the respective organizations.

Form Approved
OMB No. 9000-0095
Expires Oct 31, 2004

REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract Clause) (See Instructions on back)

PLEASE DO NOT RETURN YOUR COMPLETED FORM TO THE ABOVE ORGANIZATION. RETURN COMPLETED FORM TO THE CONTRACTING OFFICER.

1.a. NAME OF CONTRACTOR/SUBCONTRACTOR	c. CONTRACT NUMBER	2.a. NAME OF GOVERNMENT PRIME CONTRACTOR	c. CONTRACT NUMBER	3. TYPE OF REPORT (X one)
Ultraviolet Sciences, Inc.	Same as 2.c.	Same as 1.a.	FA9550-04-C-0032	a. INTERIM / X b. FINAL
b. ADDRESS (Include ZIP Code) 9189 Chesapeake Drive San Diego, CA 92123	**d. AWARD DATE** (YYYYMMDD) 2003-10-01	**b. ADDRESS** (Include ZIP Code) Same as 1.b.	**d. AWARD DATE** (YYYYMMDD) Same as 1.d.	**4. REPORTING PERIOD** (YYYYMMDD) a. FROM 2003-10-01 b. TO 2004-07-31

SECTION I - SUBJECT INVENTIONS

5. "SUBJECT INVENTIONS" REQUIRED TO BE REPORTED BY CONTRACTOR/SUBCONTRACTOR (If "None," so state)

NAME(S) OF INVENTOR(S) (Last, First, Middle Initial) a.	TITLE OF INVENTION(S) b.	DISCLOSURE NUMBER, PATENT APPLICATION SERIAL NUMBER OR PATENT NUMBER c.	ELECTION TO FILE PATENT APPLICATIONS (X) d. (1) UNITED STATES (a) YES	(1) UNITED STATES (b) NO	(2) FOREIGN (a) YES	(2) FOREIGN (b) NO	CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER (X) e. (a) YES	(b) NO
N/A	N/A	N/A						

f. EMPLOYER OF INVENTOR(S) NOT EMPLOYED BY CONTRACTOR/SUBCONTRACTOR		g. ELECTED FOREIGN COUNTRIES IN WHICH A PATENT APPLICATION WILL BE FILED	
(1) (a) NAME OF INVENTOR (Last, First, Middle Initial) None	(2) (a) NAME OF INVENTOR (Last, First, Middle Initial) None	(1) TITLE OF INVENTION N/A	(2) FOREIGN COUNTRIES OF PATENT APPLICATION N/A
(b) NAME OF EMPLOYER	(b) NAME OF EMPLOYER		
(c) ADDRESS OF EMPLOYER (Include ZIP Code)	(c) ADDRESS OF EMPLOYER (Include ZIP Code)		

SECTION II - SUBCONTRACTS (Containing a "Patent Rights" clause)

6. SUBCONTRACTS AWARDED BY CONTRACTOR/SUBCONTRACTOR (If "None," so state)

NAME OF SUBCONTRACTOR(S) a.	ADDRESS (Include ZIP Code) b.	SUBCONTRACT NUMBER(S) c.	FAR "PATENT RIGHTS" d. (1) CLAUSE NUMBER	(2) DATE (YYYYMM)	DESCRIPTION OF WORK TO BE PERFORMED UNDER SUBCONTRACT(S) e.	SUBCONTRACT DATES (YYYYMMDD) f. (1) AWARD	(2) ESTIMATED COMPLETION
University of Minnesota	200 Oak Street SE, Suite 450, Minneapolis, MN 55455	N/A	See agmt	2001-07	Development of MHCD cathode substrate processing techniques	2003-10-2	2004
Old Dominion University	4507 Hampton Blvd., 2033 Hughes Hall, Norfolk, VA 23508	N/A	See agmt	2001-07	Optimization and testing of MHCD device designs	2003-10-27	2004

SECTION III - CERTIFICATION

7. CERTIFICATION OF REPORT BY CONTRACTOR/SUBCONTRACTOR (Not required if: (X as appropriate)) X SMALL BUSINESS or ☐ NONPROFIT ORGANIZATION

I certify that the reporting party has procedures for prompt identification and timely disclosure of "Subject Inventions," that such procedures have been followed and that all "Subject Inventions" have been reported.

a. NAME OF AUTHORIZED CONTRACTOR/SUBCONTRACTOR OFFICIAL (Last, First, Middle Initial)	b. TITLE	c. SIGNATURE	d. DATE SIGNED

DD FORM 882, DEC 2001 PREVIOUS EDITION IS OBSOLETE. Reset

Appendix D. Matrix of substrates and full devices produced including test results.

Date Deposted (Sent)	Sample #	Appx. Dielect. Thick., Micron	Appx. Breakdown Volt.	Post Heat Time, min.	Post Heat Temp., C	NOTES, UMN	NOTES, ODU
(11/24/2003)	1-4	80-100	700-850	N/A	N/A	3-Layer Samples, No Hole Sent 3 Samples on 11.24.03 To ODU	
(12/12/2003)	1-4	120-180	~1000	N/A	N/A	3-Layer Samples, No Hole Sent 3 Samples on 12.12.03 To ODU	
(12/29/2003)	1-4	125-200	900	N/A	N/A	3-Layer Samples, .75 mm Hole Sent 3 Samples on 12.29.03 To ODU	3rd Layer delaminated in the ultrasonic bath
(1/16/2004)	1-4	200	1100	N/A	N/A	2-Layer Samples, .75 mm Hole Sent 3 Samples on 1.16.04	
(2/2/2004)	1-4	200-300	1300	N/A	N/A	2-Layer Samples; .5, .75, 1.0, 1.5, 2.0 mm Hole Diameters Sent 2.2.04	Holes were spaced too far apart on all samples, thus, the none were tested.
	5-7	200-300	1300	N/A	N/A	2-Layer Samples; .25, .5, .75, 1.0, 1.5 mm Hole Diameters Sent 2.2.04	
2/20/2004	1	N/A		N/A	N/A	Destroyed Upon Removal	See report
	2	N/A		60	500-700	Heat Treated, .75mm hole	
	3	500		60	500-700	Heat Treated, .75mm hole	
	4	500		N/A	N/A	Destroyed Upon Removal	
2/25/2004	1	N/A				#1-Destroyed Upon Removal	See report
	2	N/A				#2-Destroyed Upon Removal	
	3	450-500		30	500-700	Sprayed 250 micron coating in 2 stages. Each had a .75 mm hole	
	4	450-500		30		#4 sent 3/1/04 as #4; #3 sent 3/1/04 as #5	
2/27/2004	1	400-450	1990+	45	500	-Sprayed 3rd layer after heating -#1 Destroyed upon removal, replaced replaced with sample from previous set's breakdown test -.75 mm hole -Sent 3/1/04 as #3	See report
	2	400-450	1990+	45	500	-Sprayed 3rd layer after heating -.5 mm hole	
	3	400-450	1990+	45	500	-Sprayed 3rd layer after heating -1 mm hole -Sent 3/1/04 as #1	
	4	400-450	1990+	45	500	-Sprayed 3rd layer after heating -.75 mm hole -Sent 3/1/04 as #2	
3/12/2004	1	300	1990+	20	500-700	-.75 mm hole -9.6% Rel. porosity	See report
	2	300-350	1990+	20	500-700	-.75 mm hole -Sent to Randy Cooper	
	3	300-350	1990+	N/A	N/A	-.75 mm hole -Sent to Randy Cooper	
	4	300-350	1990+	N/A	N/A	-.75 mm hole -Broke down once at 1560 V, then held full 2 kV after (did not destroy sample) -18.0% Rel. Porosity	
4/9/2004 (4/12/2004)	1	150-300	1990+	30	500-600	-.75 mm hole -Ultrasonically cleaned substrate in acetone before spraying; 5 mins -Ultrasonically cleaned substrate in methanol after baking; 5 mins -Sent #1 to ODU 4/12/04	See report
	2	150-300	1990+	30	500-600	-No special notes for #2, refer to #1 -Sent #2 to ODU 4/12/04	
	3	150-300	N/A	N/A	N/A	-The (#3) substrate cracked in half when attempting to remove it from the mask	
	4	150-300	1990+	30	500-600	-No special Notes for #4 as of 4/12; refer to notes for #1 -#4 Remained at UMN	
(7/9/04) 7/2/2004		380-400	-	-	-	-Relatively even dielectric layer but thick, relatively uneven 3rd layer -This set has the new 'filled hole'	
7/6/2004	A	380-400	-	-	-	-Both layers are even -Slightly thinner 3rd layer -A spark occurred through the hole at 850 V, but it was not a breakdown.	
	B	380-400				-This sample was not hi-pot tested	

Appendix E. MHCD lamp driver specification.

1. **Description:** The power supply defined in this document is intended to drive a MHCD lamp in both high repetition-rate pulsed and dc operating modes. The lamp load (with a 100 μm thick Al_2O_3 dielectric – ε_r=9.8) has a capacitance of 88 pf/cm^2. Assuming a maximum UV output power of 100 W, a minimum efficiency of 5%, and a maximum UV power density of 1 W/cm^2, the load parameter bounds are:
   $C_L \geq 8800$ pf, $R_L \geq 20\ \Omega$ (assuming 200 V operating voltage),

2. **Performance Specifications**

<u>Power Input:</u>

120 VAC, 60 Hz, 1 phase, 20 A

<u>Power Output</u>

Trigger voltage: 1000 V peak, 10 ns risetime into an 880 – 4,400 pf load.
Continuous: 200 V, 1 A
Pulsed: 200 V, 1 A pulses, pulse width = 10 ns – 100 ns, prf = 100 kHz, each pulse starts with the trigger pulse above.

Output on coax cable with suitable connector (6' output cable supplied with unit)

Controls Inputs

Power On/Off switch, Standby/Run switch, Mode switch (dc or pulsed), Output Voltage set point (10 turn pot), Repetition Rate (10 turn pot)

Controls Outputs

Power On indicator, Standby/Run indicator, Mode indicator, Output Voltage (LCD), Repetition Rate (LCD)

3. **Physical Specifications**

<u>Dimensions:</u> ≤5U high, 19" rack mount, 24" deep.
<u>Weight:</u> TBD (<50 lb)
<u>Electrical connections:</u> 1 IEC connector for AC input, TBD coax connector for output.
<u>Controls connections:</u> N/A, all local
<u>Cooling requirements:</u> 300 CFM air cooling

4. **Environmental Specifications**

<u>Ambient temperature:</u>

Operational: 10°C – 70°C
Non-operational: -10°C – 85°C

<u>Relative humidity:</u>

Operational and non-operational: <85%, non-condensing.